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The Evaluation of Weaning Weight, 12-month Weight and 12-month Type Score in the Selection of Replacement Heifers

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THE EVALUATION OF WEANING WEIGHT, 12-MONTH WEIGHT AND 12-MONTH TYPE SCORE IN THE SELECTION OF REPLACEMENT HEIFERS

BY

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This thesis is approved as a creditable, independent investigation by a candidate for the degree, Master of Science, and acceptable as meeting the thesis requirements for this degree; but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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INTRODUCTION

The beef cattle outlook at present is one which demands attention if the needs of the future are to be met. The United States Department of Agriculture has estimated a need for one-third more meat production by 1975. Such an increase is attributable only to the rising population demands and does not reflect increased purchasing power.

In addition to the rising need for greater beef production, it is equally important that this beef be produced as economically as possible. The beef cattle industry is one of the major sources of rural income in South Dakota. According to the South Dakota Crop and Livestock Reporting Service, the state ranks fourth in numbers of beef cows on farms and ranches as of January 1, 1960. They also reported that sales from cattle and calves amounted to approximately 37 percent of the cash farm income (1954-1958 average). Any improvement that will result in a more effective selection program for replacement heifers could have a significant effect on the economy of the state.

The need for additional meat production plus the importance of the beef cattle industry to South Dakota presents a definite challenge to beef cattle breeding research. This challenge must be met by improving the performance of economic characters among the present pool of livestock by the effective use of genetic variation. Since the usefulness and the economic value of the individual animal depends on several things, and these are not likely all to be equally important or all to be independent of each other, it becomes economically unwise to select for any one characteristic alone. A selection index allows extra merit in one characteristic to offset slight defects in another by combining into one figure the credits and penalties given each animal according to its superiority or inferiority in each trait. Hence, an animal with unusually high merit in one trait is not likely to be culled due to a slightly low merit in another. However, by selecting for the traits singly or by setting independent culling levels, such animals might be discarded, regardless of the superiority or inferiority of their other traits.

Pertinent to the effective use of genetic variability and the construction of an efficient selection index is the estimation of genetic and environmental interrelationships of those traits that influence practical value. The correct relative weights to be placed on each characteristic in a selection index depends on its heritability and on its economic importance. There is always the danger here of making mistakes in estimating the heritability and the correct economic values of the characteristics involved.

The objective of this study then is to obtain an efficient selection method for selecting replacement heifers having improved breeding value for those traits considered in the index. The traits under consideration in selecting these heifers are weaning weight, 12-month weight and 12-month type score. Some of the heifers in this study were from inbred lines, hence, the influence of inbreeding on weaning weight, 12-month weight and 12-month type score was investigated.

REVIEW OF LITERATURE

Age Correction Factors

The age of an animal has been shown to have a significant effect on the weight of the animal. Birth dates of calves normally have a range of two to three months each calving season. In beef cattle breeding investigations where it becomes desirable to have individual weights of the animals at constant ages, such variation in birth date has to be considered. Correction factors to adjust for this variation in age have been developed by several workers using different methods.

Factors for correcting pig weights to a standard age of 154 days were presented by Lush and Kincaid (1943). These workers assumed from an inspection of growth curves published for pigs that the weight-age curve could be expressed as a quadratic equation. This premise was based on the assumption that the daily gain in pounds increases by a constant amount each day, instead of the rate of gain being constant. The following data were used when expressing the growth curve as a quadratic equation: The average pigs gained 1.39 and 1.75 pounds per day at 126 and 182 days of age, respectively. The average weight at 154 days of age was 142.5 pounds. Assuming that the daily gain in pounds (Y) increases by a constant amount each day between ages 126 and 182 days, the differential of weight with respect to age is:

$$\frac{Y-1.75}{X-182} = \frac{1.75-1.39}{182-126}$$

Where X = age in days, Y = daily gain in pounds. After integrating and solving for the constant by substituting weight (W) = 142.5 when X = 154 the following equation is obtained:

$$W = .0032143\ X^2 + .58\ X - 23$$

The equation for adjusting weights to an age of 154 days becomes:

$$\hat{W} = Z\ \frac{142.5}{0.0032143\ X^2 + 0.58\ X - 23}$$

Where Z is the actual weight at age X, and $\hat{W}$ is the adjusted weight.

A method for estimating weaning weights of range calves at a constant age when all weights are taken on the same day was devised by Koger and Knox (1945). The regression coefficient of weight on age was found to be positively correlated with the average weaning weight of the calves. This factor made necessary the use of a variable regression coefficient. The equation used by the authors for correcting weight to a constant age is:

$$W = w + db$$

Where W is the corrected weight, w the weight at weaning, d the standard age minus the age at weighing and b the regression coefficient of weight on age. The equation adjusts for differences in birth dates as well as for age and is felt to be more satisfactory for some purposes than methods which do not take into account seasonal influence on growth rate.

Johnson and Dinkel (1951), working with monthly weights taken from birth to weaning on 297 high grade and purebred Hereford calves, found that growth from birth to 155 days is practically an additive effect. However, thereafter growth continued at an apparently diminishing rate to 225 days--the limit of the data available. Two sets of linear correction factors were calculated using the method of Bywaters and Willham (1935) and Whatley and Quaife (1937). The intercept of the least squares line of best fit with the age axis was used to determine the point of origin of weight on age. This intercept was then used in the equation:

$$Y = W \frac{(A - I)}{(X - I)}$$

Where Y is the corrected weight, W is the actual weight at age X, A is the standard age, I is the intercept and X is the actual age in days. The standard ages used were 155 days and 190 days. Multiplicative factors were calculated for correcting weights at all ages to the two standard ages by using the formula: $\frac{\text{Standard Age} - \text{Intercept}}{\text{Actual Age} - \text{Intercept}}$. The authors developed another set of correction factors by employing the use of a quadratic equation. The calculations used were similar to those used by Lush and Kincaid (1943).

The experimental investigation of data collected from a herd of grade Hereford cattle at the Squaw Butte-Harney Experiment Station in Central Oregon showed that the age of a heifer has a significant effect on her yearling weight. In this study using the records of 157 grade Hereford cows and their 376 offspring, Hitchcock et al. (1955) found a significant partial regression coefficient of 1.09 pounds per day for the effect of age on the yearling weight of heifers. The authors also found a significant partial regression coefficient, representing the effect of age on the yearling weight of steers, to be 1.55 pounds per day. All corrections for age in this study were made along the regression line of weight on age. The correction equation was CW = W - ba + bK; where CW was the corrected weight, W was the actual weight, a was the actual age, K was the constant age and b was the slope of the regression line.

Minyard (1959), working with weaning weight records of 2351 Hereford and Angus calves collected from 1951 through 1957 in cooperation with the South Dakota Extension Service, found that the age of the calf at weaning has a highly significant influence on its weaning weight. This linear regression of weight on age was 1.20. Two methods of calf age adjustment were evaluated in this study. The first method is based on the growth rate of the individual calf while the second method is an evaluation of correction factors developed by Johnson and Dinkel (1951). In method one, the 190-day age adjusted weaning weight was computed using the following equation: Age Adjusted Weight = $\frac{\text{Actual Weight} - \text{Birth Weight}}{\text{Actual Age}}$ X 190 + Birth Weight. The correction factors used in method two were computed by linear regression of weight on age. According to the authors method two appeared to be the most efficient, removing 90 percent of the variance due to age of calf.

Age of Dam Correction Factors

Numerous studies have been made concerning the influence of age of dam on birth weight and weaning weight. However, very little literature pertaining to age of dam effect on weights of older age groups is available.

Koch and Clark (1955) investigated the influence of age of dam on fall yearling weight. The study was made on fall yearling weights from 5952 Hereford heifers approximately 18 months old. The records were accumulated during the period 1926 to 1951 at the U. S. Range Livestock

Experiment Station, Miles City, Montana. The authors point out that there is less age of dam effect at fall yearling age than at weaning. This is probably due to the fact that calves having a limited milk supply prior to weaning tend to grow more rapidly thereafter. The spread between weights at yearling age are therefore reduced and age of dam differences are not as prominent.

Two methods (A and B) of calculating correction factors for age of dam were presented by Koch and Clark. Method A compares averages of all records made at each age while Method B compares records made by the same cow at two different ages. Due to selection, Method A may be biased upward and Method B biased downward. Hence, the true age effect would be between the two methods as p/1-p, where p is the repeatability of adjacent weaning weights. The age correction factors for fall yearling weight derived from the combined estimates were:

Age:	3	4	5	6	7	8	9	10
C. F.:	24	13	3	0	2	4	7	14

Six years of age was selected as a base for comparisons.

Minyard (1959), using weaning weight records on 2023 calves, estimated the influence of age of dam by the same methods outlined by Koch and Clark. Data available for estimating the age of dam influence by Method B were 456 pairs of records representing 378 different cows. The age of dam differences found by the author were significant at the 0.01 level of probability. Maximum production was reached at 8 years of age. The combined estimates obtained were:

Age:	2	3	4	5	6	7	8	9	10	11
C. F.:	71	35	22	14	4	3	0	9	22	24

Effects of Inbreeding

The literature dealing with inbreeding experiments with cattle covers only the last three decades and is not extensive. With few exceptions inbreeding of large animals has resulted in reduced vigor as exhibited by slower growth, smaller size, greater mortality and lower production and fertility. Most workers, however, have indicated that inbreeding acts more to lower the rate of development than it does to limit eventual size and production at maturity.

Data collected over a period of 24 years, from 1921 to 1944, on body weight and other measurements of females in the University of California Jersey herd were analyzed by Rollins (1949). The effects of inbreeding upon growth during the period from birth to 56 months of age were investigated from records on 322 animals. Coefficients of inbreeding averaged 15 percent, while for individual animals it ranged from zero to 47 percent. By employing groups where the range of inbreeding was at least 25 percent, and in which more than two levels of inbreeding were present, the linear regression of 12 month weight on the percent inbreeding was found to be significant at the 0.1 percent level of probability. At six and twelve months of age, an increase of one percent in inbreeding caused a decrease of 0.47 and 0.34 percent in mean weight respectively. In a comparison of inbred and outcrossed animals it appeared to the authors that the inbreds were smaller at birth and grew more slowly up to about six months of age, but at some time between the sixth and twelfth month of age the inbreds began to grow more rapidly than the outcrosses and continued to do so for the period covered by the study.

The effects of mild inbreeding on weight of Holstein-Friesian cattle at various ages were reported by Nelson and Lush (1950). This study was an analysis of the records of 176 animals, accumulated between 1930 and 1942. Inbreeding coefficients ranged from 0 to 28 percent, with an average of five percent for the entire group. Intra-sire regressions of weight on inbreeding, for six month and one year age groups were - 0.72 and - 2.74 per one percent inbreeding, respectively. The latter regression was significant at the five percent level of probability. Their study indicates that inbreeding results in lighter calves at birth, and slower gains during the first two years of life.

Koch (1951), made a study of the effects of inbreeding on weaning weights of 745 Line 1 Hereford calves at the U. S. Range Livestock Experiment Station at Miles City, Montana during the period 1938 through 1948. The average inbreeding of all the calves was 12.4 percent. The regression of weaning weight on the inbreeding of the individual calf was - 0.48 pounds.

Burgess _et al_. (1954), utilized the weaning weight records of 546 conventional type Hereford calves, dropped during the years 1946 to 1951 in estimating the effects of inbreeding. The data were collected at the San Juan Basin Experiment Station, Fort Lewis A. and M. College, Hesperus, Colorado. The inbreeding coefficients of the calves ranged from 0 to 50, with the majority of the calves falling in the 0 to 20 range. A deviation from the average weaning weight of - 1.76 pounds per one percent inbreeding of the calf was reported. The investigators found a significant deviation from linearity for calf inbreeding effects.

Zoellner (1957), found the effects of inbreeding on weaning and 18-month weight to be curvilinear. The records on which this study was based represents 143 heifers raised at three South Dakota Experiment stations during the period 1953 to 1955. The weaning weights of the heifers were found to be significantly influenced by the effects of inbreeding. The linear reduction in weight was - 1.76 pounds per one percent inbreeding. Reduction in 18-month weight and type score as a result of inbreeding were reported to be non-significant. The inbreeding of the heifers ranged from zero to 25 percent with approximately 80 percent of the calves falling in the zero to 15 range.

Heritability Estimates

Yearling (12-month) Weight

Heritability is defined as that portion of the total variation which is due to additive genetic effects. Mass selection on individual merit for highly hereditary traits allows rapid progress. The heritability of yearling weight according to the limited number of estimates available appears to be over 40 percent. It would therefore be a likely characteristic to select for in bringing about increased production through the replacement heifers used in a herd.

Knapp and Nordskog (1946), using records from 177 steer calves from 23 sires at the U. S. Range Livestock Experiment Station, Miles City, Montana, presented the first estimate known to have been made of the heritability of quantitative traits in beef cattle. The authors reported the heritability of 18-month weight of heifers as .61 using the paternal half-sib correlation method.

Data on 1694 fall yearling weights taken at the U. S. Range Livestock Experiment Station, Miles City, Montana, during the period 1926 to 1951, were used by Koch and Clark (1955[a]) to estimate heritability on a paternal half-sib basis. The estimated heritability for fall yearling weight was .47.

In additional studies at the Miles City Station, Koch and Clark (1955[b]) analyzed records on 1623 calves and their 822 dams. The heritability estimate calculated from the regression of offspring on dam was .43 for fall yearling weight.

Long yearling weights of 305 heifers were analyzed by Wagnon and Rollins (1959) using the paternal half-sib method for estimating heritability. These heifers were in two experimental range herds, A and B. Both herds were of similar breeding and managed alike except that in herd A the cows and heifers were supplemented during the fall and winter (post weaning) when the range was nutritionally deficient, while the cows and heifers in herd B were not supplemented. Herd B heifers invariably lost weight during this period. Heritability estimates of long yearling weight were .44 for herd A and - 0.19 for herd B. The low heritability estimate for herd B was attributed to the fact that young growing animals going from a period of weight loss into a period of weight gain have internal physiological adjustments to make. In the analysis used these effects would inflate the within sire variance component to a much greater extent than the variance component due to sire differences thus resulting in a low heritability.

Weaning Weight

A survey of the literature by Brown (1958), indicates considerable range in the estimates of heritability of weaning weight. Most of the estimates, however, in the literature reviewed vary from .12 to .52.

A study was made by Knapp and Nordskog (1946), on 177 steer calves from 23 sires at the U. S. Range Livestock Experiment Station, Miles City, Montana, to determine the heritability of weights at various ages. Two methods were used in deriving the effects of heredity on weaning weights. The intra-sire half-sib correlation obtained by analysis of variance and the sire:progeny regression obtained by covariance analysis yielded heritability estimates of 12 percent and zero percent respectively.

Gregory et al. (1950), estimated the heritability of weaning weight from data collected at the North Platte and Valentine Substations of the Nebraska Agricultural Experiment Station. The North Platte data were collected over two periods: 33 records made during 1936, and a total of 237 records collected from 1944 through 1947. The 270 records in all were the progeny of six bulls. Data on 69 offspring from four sires were available from the Valentine Substation during the years 1935 to 1936. Calves from both stations were dropped in the spring and placed on grass with their dams until weaning. The data were treated separately at the two stations and analyzed on an intra-year, intra-lot basis. Heritability estimates based on paternal half-sib correlations were .26 for the North Platte Station and .52 for the Valentine Station.

Shelby et al. (1955), estimated the heritability of weaning weight from data collected during a ten year period (1942 to 1951) at the U. S. Range Livestock Experiment Station at Miles City, Montana. The data consisted of records of 635 Hereford steers from grade cows mated to 88 sires from nine inbred lines. Heritability within year-line subgroups was computed by the paternal half-sib correlation method. The estimate of .23 obtained was in the general range of previous estimates.

In another extensive investigation of economic characteristics in range beef cattle at the Miles City Station, Koch and Clark (1955[a] and 1955[b]) used three different methods of estimating the heritability of weaning weight. An intra-year and line heritability of .24 was computed by the paternal half-sib correlation method. The available data for this method were the records of 4553 weaning weights accumulated over the period 1929 to 1951 from 137 different sires. The weaning weights were adjusted to a standard age of 182 days and corrected for sex and the influence of age of dam. Using the methods, regression of offspring on dam and regression of progeny average on sire, heritability estimates of .11 and .25 for weaning weight were obtained. In the regression of offspring on dam study, records on 4234 calves and their 1231 dams were available. By grouping pairs of records into subclasses according to the years the cows were born and the years the calves were born, the year effect and the age of dam effect were eliminated. The regression of offspring on sire was the third method used where weaning weights were available for offspring from 85 sires. The data were grouped into subclasses according to the year the sire was born and the year the calves were born thus removing the average effects of years. The progeny average was then regressed on the sires record.

Dinkel and Musson (1956), using records made available by the South

Dakota Extension Service on 646 calves sired by 62 bulls, arrived at a heritability estimate for weaning weight of 36 percent. Due to large environmental differences from year to year and ranch to ranch the analysis was made by comparing sires in the same year on each ranch.

Chambers et al. (1958), estimated the heritability of 210-day weight from first calf heifers to be approximately 30 percent. The data for this study included 59 daughter-dam pairs from a high grade Hereford herd of approximately 100 cows at the Fort Reno Experiment Station, Oklahoma. The statistical procedure used to obtain the estimates was an intra-sire, intra-season regression of the heifers performance on that of her dam.

Brown (1958), reported on the heritability of weight and measurements of beef calves. The animals used in this study included 225 Hereford and 212 Aberdeen Angus calves which were maintained at the Arkansas Agricultural Experiment Station, during the period 1940 to 1953. The least squares analysis was made on weights adjusted to a standard age of 240 days. Corrections were also made for differences due to sex, year and season of birth of calf and age of dam. The heritability estimates for weaning weight derived by the paternal half-sib correlation method were 26 percent for the Hereford data and 11 percent for the Aberdeen Angus data.

Yearling (12-month) Type Score

A heritability estimate of .18 for yearling type score was computed by Koch and Clark (1955[a]) using the paternal half-sib correlation method. The data evaluated in their study were the fall yearling type scores of 1483 calves raised at the U. S. Range Livestock Experiment Station, Miles City, Montana. Records were accumulated over the period 1936 to 1951.

In another study at the Miles City Station, Koch and Clark (1955[b]), reported a heritability of .14 for fall yearling type score using the regression of offspring on dam method of analysis. The data which afforded this estimate included fall yearling scores on 797 calves and their 443 dams.

At the Georgia Coastal Plain Experiment Station, McCormick et al. (1956), estimated the heritability of type score for yearling bulls and heifers as 12 and 15 percent respectively. Their estimates were obtained by the paternal half-sib correlation method. The data consisted of scores of 148 heifer and 142 bull calves raised under farm conditions. Scores were available in ten different seasons on progeny of two or more sires.

Zoellner (1957), estimated the heritability of 18-month type score at 65 percent by the paternal half-sib analysis. The 126 heifer type scores were analyzed on an intra-year, intra-ranch basis. The records were accumulated over the period 1948 to 1952 at three South Dakota Experiment Stations. The animals represented were the progeny of fifteen sires.

Genetic and Environmental Correlations

Knowledge of the genetic and environmental relationship among the important economic characteristics in beef cattle is important in establishing a basis of selection for the simultaneous improvement of two or more characters.

Koch and Clark (1955[a]) made an extensive study of the genetic and environmental correlations among economic traits in beef cattle at the U. S. Range and Livestock Experiment Station, Miles City, Montana. The data analyzed in this study were the records of 4553 weaning weights, 3831 weaning scores, 1694 fall yearling weights and 1483 fall yearling scores. The weaning and fall yearling weights were accumulated over the period 1929 to 1951 from 137 different sires. The weaning and fall yearling type scores were obtained over the years 1936 to 1951 and involve 124 different sires. Genetic and environmental correlations between weaning weight and yearling weight were .54 and .46 respectively. The authors also reported genetic and environmental correlations between yearling weight and yearling type score (.49 and .61 respectively) and between weaning weight and yearling type score (.23 and .27 respectively).

In a more recent study, Carter and Kincaid (1959), reported on data from 195 steers and 190 heifers, the progeny of 36 sires at the Virginia Agricultural Experiment Station. They reported a genetic correlation between 182-day weight and feeder grade in steers of .49. Among the heifers, a genetic correlation of .31 was calculated between 182-day weight and feeder grade. In addition, the authors listed a genetic correlation of .50 between 182-day weight and yearling grade for heifers.

SOURCE OF DATA

The data for this study came from records on 285 purebred heifers, raised by the South Dakota Agricultural Experiment Station under a cooperative project with the North Central States' Regional Beef Cattle Breeding Project. Twenty six sires were represented in this study. The heifers were calved over an eight year period at the Antelope Range Field Station, Buffalo, South Dakota.

The Antelope Range Field Station is located in northwestern South Dakota, in the drier part of the chestnut soil zone. Average annual precipitation is from 12-14 inches, and quite variable from year to year. Temperatures range from below zero in the winter to as high as 100 degrees in mid-summer. The vegetation which has developed under these climatic and soil conditions is the mixed prairie type consisting of shortgrasses, midgrasses and forbs. Dominant among the medium height grasses are western wheatgrass, green needlegrass and needle-and-thread. The major short grasses are blue grama grass, threadleaf sedge, needleleaf sedge, and buffalo grass.

Experimental beef cattle breeding projects at the Antelope Range Field Station were initiated in 1947. The original cow herd was leased prior to 1949 at which time it was purchased by the experiment station from cattle breeders in the state. In 1952, four one-sire inbred lines and one four-sire control were formed at the Antelope Station as part of a long-range inbreeding-selection study. Due to the necessity of increasing the size of the herds, no selection was practiced on the heifers prior to the 1953 calf crop.

The heifer calves in this study were carried through to weaning without supplemental feeding. They were weaned the end of October of each year, at which time they were weighed and scored for type and condition. After weaning, the heifer calves were transported to the field station at Cottonwood for wintering and summer grazing. The ration fed during the winter was calculated to produce a gain of about one pound per day. During the period 1952 to 1954, inclusive, the ration consisted of five pounds of oats, one pound 40 percent protein cake, and prairie hay free choice. The 1955 to 1959 calf crops received alfalfa hay free choice and oats sufficient to gain the one pound per day. The feeding period from weaning to approximately 12-months of age was not a constant length each year but varied in range from 178 to 219 days. The average length of the feeding periods overall years was 195 days. The weights and scores used in this study were taken at approximately 12-months of age, at the time the heifers were turned to summer pasture. They were weighed and scored for type again in the fall at approximately 18-months of age, when the selected heifers were returned to their home ranch to go into the breeding herds.

The yearling type score for each heifer calf is an average of three judges' scores, each working independently. The following scoring and coding system was used:

Score	Code	Description
1 +	17	
1	16	Show type
1 -	15	
2 +	14	
2	13	Suitable for purebred herd
2 -	12	
3 +	11	
3	10	Suitable for commercial herd
3 -	9	
4 +	8	
4	7	Not recommended for use
4 -	6	
5 +	5	
5	4	Cull
5 -	3	

The scores were coded for analytical purposes according to the code given.

Tables I and II list the mean weaning weight, 12-month weight and 12-month type score by years and sires respectively. The weaning and 12-month weights were corrected for age, age of dam and inbreeding. Correction for the effects of inbreeding on type score were also made.

TABLE I. YEAR MEANS

Year of Birth	No. of Progeny	12-month Weight (lbs.)	Weaning Weight (lbs.)	12-month Type Score
1952	15	606	419	11.40
1953	25	681	447	11.59
1954	37	635	418	10.98
1955	41	590	394	10.63
1956	42	581	393	10.82
1957	43	533	417	11.41
1958	38	679	410	11.32
1959	44	611	405	10.70
Averages	285	610	410	11.05

The means in Table I show considerable variation for 12-month weight from year to year, as indicated by the mean of 681 pounds for heifers born in 1953 and the mean of 533 pounds for the 1957 heifers. Weaning weights varied from a high of 447 pounds in 1953 to a low of 393 pounds in 1956. The 12-month type scores were fairly uniform, ranging from 10.63 in 1955 to 11.59 in 1953.

Table II shows the variation that exists between sires for the three traits. It should be recognized here that the sire averages are not free of the large yearly differences previously indicated. The means vary from a high of 693 pounds for sire 432 to a low of 505 pounds for sire 529. Variation in weaning weight is indicated by a range of 374 to 444 pounds. The means for 12-month type score range from 10.06 to 12.63 with an extreme low of 8.60 for sire 840.

TABLE II. SIRE MEANS

Sire	No. of Progeny		12-Month Weight (lbs.)	Weaning Weight (lbs.)	12-Month Type Score
821	5		559	387	11.44
512	25		617	410	10.63
711	7		603	374	10.06
810	6		614	404	11.53
836	6		632	419	10.29
82	6		630	414	10.87
840	5		569	375	8.60
014	43		597	413	11.83
432	10		693	430	12.63
718	3		644	388	11.56
101	37		666	444	10.72
300	20		568	401	11.53
012	32		616	411	10.75
529	3		505	375	11.33
436	5		568	416	10.45
433	20		570	386	10.60
319	2		588	404	10.24
321	8		560	380	10.80
233	9		633	436	10.64
132	3		615	398	10.32
032	3		603	391	10.76
920	12		598	389	11.70
402	4		620	443	12.00
219	5		618	426	11.60
030	4		569	387	11.00
003	2		623	420	10.50
Total	285	Averages	610	410	11.05

STATISTICAL ANALYSIS

Age Correction Factors

The age adjustment factors in this study for correcting the weaning weights to a constant age of 190 days were developed by Johnson and Dinkel (1951). The weaning weight records, used by Johnson and Dinkel in computing the linear regression of weight on age, were from calves raised under conditions similar to those of this study. To simplify the correction of numerous weights, multiplicative factors were calculated for correcting weaning weights at all ages. These factors were calculated using the following formula:

$$\text{Factor} = \frac{\text{Standard Age} - \text{Age Intercept}}{\text{Actual Age} - \text{Age Intercept}}$$

where the age intercept is the intercept of the regression line on the age axis.

Having corrected the weaning weights for age, the following formula was used for obtaining the 12-month weights corrected for age:

$$W = A + B$$

where W is the age corrected 12-month weight, A is the age adjusted weaning weight, and B is the gain made by the heifer from weaning to approximately 12-months of age.

Age of Dam Correction Factors

The age adjusted records from 241 heifer calves were suitable for use in estimating the influence of age of dam on 12-month weight. Two methods of calculating correction factors for age of dam were presented by Koch and Clark (1955). The first, designated Method A, is a comparison of averages of all records made at each age and the second, designated Method B, compares records made by the same cow at two different ages. Both methods may be biased from the true age effect by concurrent selection practiced in the herds. However, the biases are in opposite directions, Method A being biased upward and Method B biased downward from the true age of dam effect. A thorough discussion of these biases is given by Lush and Shrode (1950). The real age effect has been shown to lie between the two estimates, Method A and Method B. The difference between Methods A and B may be proportioned as p/1-p, where p is the repeatability of adjacent 12-month weights.

Both methods were used in estimating the influence of age of dam. Using Method A, the average 12-month weights were calculated for each age of dam class. For Method B, all cows having records at two or more consecutive ages were selected and the age of dam class averages computed. Table III shows the number of cows having calves at each age and the number of cows having calves at each pair of ages. To obtain the combined estimates, the differences between methods A and B were proportioned as p/1-p. To compare the accuracy of the combined estimates with data uncorrected for age of dam influences, two variance analyses were computed and the age of dam mean square was calculated on a within year subclass basis.

TABLE III. NUMBER OF RECORDS USED IN ESTIMATING THE INFLUENCE OF AGE OF DAM

Method A		Method B	
Age of Dam	Cows Having Calves at Each Age	Age of Dam	Cows Having Calves at Each Age
3	55	3-4	11
4	41	4-5	13
5	33	5-6	10
6	26	6-7	6
7	27	7-8	5
8	21	8-9	7
9	22	9-10	5
10	9	10-11	1
11	7		
Total	241		58

Effects of Inbreeding

The data used for the inbreeding study included records from 285 heifers raised during the period 1952 to 1960, inclusive. The weaning and 12-month weights for all the animals were adjusted for age and age of dam differences. Age correction factors developed by Johnson and Dinkel (1951) were used to adjust the weaning weights to a constant age of 190 days. The 12-month weights were adjusted for age using the procedure previously outlined under age correction. The age of dam correction factors used were developed by Minyard (1959). The inbreeding coefficients were determined by using the methods outlined by Wright (1922) and Emik and Terrill (1949).

The effects of inbreeding of an animal on its weaning weight, 12-month weight, and 12-month type score were determined by using the variance--covariance analysis outlined by Snedecor (1956). The regressions were calculated from within year-sire subclasses. The data were corrected for inbreeding effects according to these linear regression coefficients.

Statistical analyses were made to determine whether the regressions of weaning weight, 12-month weight and 12-month type score on inbreeding are curved. The second degree polynomial method was used for this purpose and is described by Snedecor (1956) in his chapter on curvilinear regression.

Heritability Estimates

Heritability estimates obtained for weaning weight, 12-month weight, and 12-month type score in this study were calculated by the paternal half-sib correlation method described by Lush (1948). The data available for the paternal half-sib analysis included records from 285 heifers, representing 26 sires. The weaning and 12-month weights were corrected for age, age of dam and inbreeding effects. Correction for inbreeding on 12-month type score was also made. The factors used for correcting the weaning weights to a constant age of 190 days were those developed by Johnson and Dinkel (1951). The 12-month weights were corrected for age as outlined in the procedure for age correction. Age of dam correction factors used were developed by Minyard (1959). Correction for the effects of inbreeding were developed from these data.

The expression of each trait is due to the average effects of the genes (G) which an animal inherits, plus the combined effects of environment, dominance and epistasis (E). In a random mating population, the genic correlations between half-sibs would be one-fourth, dominance correlations would be zero and the epistatic correlations would be quite small. However, in a non-random mating population where inbreeding is used, the genic correlations increase, the dominance correlations have small values and the epistatic correlations increase rapidly.

To obtain the components of variance, the intra-year variance must be separated into two mean squares; between sires and within sires. The theoretical composition of the between sires mean square is A plus K_oB, where A equals the within sire mean square, K_o is the geometric or weighted mean number of progeny within each sire group and B is the sire component. The sire components and within sire mean squares were obtained from a within year subclass analysis of variance and covariance. In calculating K_o, sires which are used in more than one year, are considered a different sire each year. Each yearly sample is an unbiased estimate of sire differences. The estimate of the additive genetic portion of the variance is obtained from the sire component. Hence, in order to obtain B (sire component), the within mean square (A) is subtracted from the between sire mean square and the difference is divided by K_o.

The fraction $\frac{B}{A+B}$ is the intraclass correlation among half-sib groups. In a random breeding population, the intraclass correlation multiplied by four represents the theoretical additive genetic portion of the total variance or heritability (h^2). However, in a partially inbred population where the relationship between half-sibs is larger than one-fourth, the multiplier is derived by the following formula presented by Lush (1948):

$$r_{GG} = \frac{4(1 + F)}{1 + F' + 6F}$$

where F equals inbreeding of the progeny and F' equals inbreeding of the parents.

The standard errors (SE) for the paternal half-sib heritability estimates obtained in this study were computed by the following method outlined by Hazel and Terrill (1945):

$$SE = \frac{4}{1 + F' + 6F} \cdot \frac{A(A+K_oB)}{(A+B)^2 \sqrt{\frac{1}{2}(K_o-1)K_on}}$$

where n equals the actual number of sires.

Genetic, Environmental and Phenotypic Correlations

The genetic and environmental correlations obtained were estimated from an intra-year analysis of variance and covariance. The procedures for this study were set forth by Knapp and Clark (1951), and the data were those used in the paternal half-sib analysis.

The phenotypic expression of a trait is due to two sources G plus E; thus:

$$X = G + E + 2Cov_{GE}$$

Since the data were analyzed on an intra-year basis, there is no reason to suspect a correlation between G and E and it is assumed to be zero. The phenotypic variance of a trait may be designated as:

$$V_x = V_G + V_E$$

The covariance between any two traits may be designated in the same manner:

$$CV_{X_1X_2} = CV_{G_1G_2} + CV_{E_1E_2}$$

The covariance components may be computed in the same manner as the variance components in the half-sib analysis.

Under the conditions of random mating, where the genetic variance in the sire components is one-fourth, the genetic and environmental variances and covariances may be calculated as follows:

$$V_G = 4V_S \qquad CV_G = 4CV_S$$

$$V_E = V_I - 3V_S \qquad CV_E = CV_I - 3CV_S$$

where:

V_G = genic component of variance

V_S = sire component of variance

V_E = environmental component of variance

V_I = within sire mean square

CV_G = genic component of covariance

CV_S = sire component of covariance

CV_E = environmental component of covariance

In a partially inbred population, where the relationship between half-sibs is greater than one-fourth, the sire component will contain more than one-fourth of the genetic variance. In this case multiplication would be by $\frac{4(1+F)}{1+F'+6F}$ instead of four, in deriving the genetic variance from the sire component. The formula used here for the multiplier was presented by Lush (1948).

The within sire mean square would also be affected by the greater relationship which exists between half-sibs in a partially inbred population. Since the genic variance derived from the sire component is greater than one-fourth, that contained in the within sire mean square will be correspondingly less.

The following algebraic equations were used to estimate the genic variance in the within sire mean square:

$$r\sigma_G^2 = \frac{1 + F' + 6F}{4(1+F)} \sigma_G^2$$

where r = relationship within half-sib groups

σ_G^2 = genetic component.

Since the sire component equals $r\sigma_G^2$ and since the within sires mean square contains $(1 - r)\sigma_G^2$, solving the following formula for X yields an estimate of the number of sire components present in the within sires mean square.

$$(1 - r)\sigma_G^2 = X \cdot \frac{1 + F' + 6F}{4(1 + F)} \sigma_G^2$$

The product of X and the sire component, subtracted from the within sire mean square, gives the environmental component. The phenotypic components are then derived by pooling the genetic and environmental components.

The following formula was used for calculating the correlations:

$$r_{X_1X_2} = \frac{CV_{X_1 X_2}}{\sqrt{(V_{X_1})(V_{X_2})}}$$

where X equals either genetic, environmental, or phenotypic components.

Selection Indices

According to Hazel and Lush (1943), selecting for traits simultaneously by using a selection index is more efficient than selection for one trait at a time or for several traits with an independent culling level for each trait.

Seven different selection indices were constructed in this study based on the following traits and combinations of those traits:

Selection Method	Trait or Traits Involved
1.	Weaning weight, 12-month weight, and 12-month type score.
2.	Weaning weight and 12-month weight.
3.	Weaning weight and 12-month type score.
4.	12-month weight and 12-month type score.
5.	Weaning weight.
6.	12-month weight.
7.	12-month type score.

The method of constructing the indices was discussed and outlined by Hazel (1943). In the present study, the data consisted of records from 285 purebred Hereford heifers born during the period 1952-1959, inclusive. The weaning and 12-month weights were corrected for differences in age, age of dam and inbreeding, and the type scores were corrected for differences in inbreeding. Methods for correcting the data for these effects have been previously outlined.

The economic value assigned to a trait was based on the relative effect that trait was assumed to have on profit when it varied one unit. Values were obtained from stocker and feeder price quotations at the Omaha market, averaged over a three-year period. The average price of 100 pounds of Good to Choice beef heifer calves was $26.90, over a 12-month period in 1957, 1958 and 1959. Choice yearling beef heifers were selling for $25.10 per hundred, and Medium to Good yearling heifers were selling for $21.53. The economic value for 12-month type score was determined by considering a unit change in type equal to a grade change from Medium and Good to Choice. The average difference in sale price between the two grades was $.89 per hundred. The average 12-month weight of heifers in the study was 610 pounds, therefore, an increase in one-third of a grade of type score would be an increase of $5.43 in income. These estimates were based on data presented by Market News (1957, 1958 and 1959). The relative economic values which were derived for use in this study are: weaning weight .27, 12-month weight .25 and 12-month type score 5.43.

The remaining statistical information required for construction of the indices was calculated from data used in this study.

In a selection index the breeding value or aggregate genetic value of an animal is the sum of its several genotypes, which are distinct for each trait involved and weighted according to the relative economic value of that trait. Defined by a formula, the aggregate genotype of an animal is:

$$H = a_1G_1 + a_2G_2 + a_3G_3$$

where G_1, G_2 and G_3 are the genetic values for weaning weight, 12-month weight and 12-month type score, respectively, and a_1, a_2 and a_3 are the relative economic values of these traits. Due to environment, dominance, and epistasis which tend to mask the genotype, animals having the highest values for H cannot be recognized directly with perfect accuracy. Hence, selection is directed toward a correlated variable (I) which is based on the phenotypic performance of each animal for the three traits.

The index (I) is defined as:

$$I = b_1X_1 + b_2X_2 + b_3X_3$$

where the X's represent the phenotypic performance of the three traits, and the b's are multiple regression coefficients, calculated to make R_{IH} as large as possible. R_{IH} is the correlation between the aggregate genotype and the index. The regression coefficients were calculated from simultaneous equations:

$$\begin{aligned}
B_1 \quad &+ B_2 r_{X_1X_2} + B_3 r_{X_1X_3} = r_{X_1H} \\
B_1 r_{X_1X_2} &+ B_2 \quad + B_3 r_{X_2X_3} = r_{X_2H} \\
B_1 r_{X_1X_3} &+ B_2 r_{X_2X_3} + B_3 \quad = r_{X_3H}
\end{aligned}$$

where $B_i = b_i \dfrac{\sigma X_i}{\sigma H}$ and r_{X_iH} is the correlation between the aggregate genotype and the i th phenotypic measurement. This correlation is derived as follows:

$$r_{X_iH} = r_{G_iX_i} \left\{ d_1 r_{G_1G_i} + d_2 r_{G_2G_i} + d_3 r_{G_3G_i} \right\},$$

where $d_i = a_i \dfrac{\sigma G_i}{\sigma H}$ and $r_{G_iX_i}$ is the correlation between genotype and phenotypic performance for each trait. The standard deviation of the breeding value (σH) is defined as:

$$\sigma H = \sqrt{a_1^2 \sigma G_1^2 + a_2^2 \sigma G_2^2 + \ldots\ldots + 2\, a_1a_2 \sigma G_1 \sigma G_2 r_{G_1G_2} + \ldots\ldots}$$

Progress in selection for improved breeding value is affected by R_{IH}, σG and the selection differential. The genetic variability is biologically fixed. The selection differential, which depends to a considerable extent upon the proportion of the herd which can be culled, will afford the breeder some opportunity for improvement. However, the greatest opportunity for increasing the progress expected from selection lies in making R_{IH} as large as possible. The amount of genetic progress expected, when a given index is used in making selections, is proportional to R_{IH}. Hence, the correlation provides a means of comparing the accuracy of the indices.

RESULTS

Age of Dam Correction Factors

The maximum production of the cows, determined by averaging the production records for each age of dam class and summing over all years (Method A), appeared to be reached at seven years of age. This age was selected as a base for comparisons. The age of dam means by year for 12-month weight are given in Table IV. Age of dam differences within

TABLE IV. AGE OF DAM MEANS

Year	3	4	5	6	7	8	9	10	11+
1952	571	600		576	695				
1953	600	699	635	672	644				
1954	548	594	608	620	592	642	537		
1955	525	567	581	563	568		566	581	
1956	440	571	544	563	533	537	569	573	656
1957	470	480	530	532	433	444	516	554	483
1958	608	594	640	626	694	635	647		639
Averages	533	579	586	573	603	583	553	573	619

year subclasses were significant at the 0.01 level of probability (Table V).

TABLE V. ANALYSIS OF VARIANCE FOR AGE OF DAM EFFECTS

Source of Variation	d.f.	Mean Square	F
Total	240		
Between Years	6	91,880	31.04 **
Age of Dam-Year Subclass	48	18,378	6.21 **
Age of Dam Within Subclass	42	7,877	2.66 **
Within	192	2,960	

** Highly Significant ($P < 0.01$)

The maximum production using Method B also appeared to be at seven years of age. The deviations computed by Method B were larger than those computed by Method A. This is just the opposite of what would be expected, since Method A is biased upward and Method B is biased downward from the true age of dam effect. It would seem more reasonable for the deviations computed by Method B to be smaller than those computed by Method A at least for cows below eight years of age. The large deviations encountered in Method B are probably due to the inadequate numbers available in computing the means for this method as indicated by the standard errors associated with these deviations. Another possible explanation might be the fact that the records used in Method B were unadjusted for year differences. Since adjacent 12-month weight records of the same cow must necessarily fall in different years, environmental variation between years would tend to influence these records.

The estimates of age of dam effects for Method A, Method B and those obtained by combining the two methods are presented in Table VI. The combined estimates were obtained by proportioning the difference between Method A and B as p/1-p, where p is approximated by the repeatability of adjacent 12-month weights. From the study of these data p was estimated as 0.38.

Using the combined estimates developed in this study, the 12-month weights previously corrected for age, were adjusted for age of dam effects. An analysis of variance for age of dam effects, using the corrected data, was made on a within year subclass basis. The within subclass variance was reduced (Table VII) but not enough to make these factors useable.

Age of dam correction factors for weaning weight, developed by Minyard (1959), are presented in Table VI. These factors were applied to the weaning and 12-month weights and used in the present study. A second analysis of variance for age of dam effects (Table VII) was made using Minyard's correction factors. The reduction in age of dam within subclass variance was greater using these factors than it was using the factors developed in this study. Although age of dam differences were not entirely removed by these factors, they were found to be the most useful of those available.

TABLE VI. CORRECTION FACTORS FOR AGE OF DAM

Age of Dam	Deviations Method A	Deviations Method B	Combined Estimates Where p/1-p = .38/.62
		Present Study	
3	70 ± 6.84	101 ± 26.88	82
4	24 ± 7.26	42 ± 14.17	31
5	17 ± 7.92	24 ± 18.61	20
6	30 ± 7.94	45 ± 15.97	36
7	0	0	0
8	20 ± 11.29	84 ± 28.91	44
9	50 ± 12.81	95 ± 18.87	67
10	30 ± 15.69	57 ± 18.87	40
11 +	- 16 ± 23.64	143 ± 0	64
		Minyard (1959)	p/1-p = .42/.58
2	80 ± 5.34	54 ± 9.09	71
3	45 ± 3.08	17 ± 4.75	35
4	30 ± 2.67	8 ± 3.29	22
5	21 ± 2.56	2 ± 3.17	14
6	4 ± 3.02	3 ± 4.03	4
7	3 ± 3.08	4 ± 4.37	3
8	0	0	0
9	8 ± 4.59	10 ± 5.96	9
10	16 ± 5.29	32 ±8.64	22
11 +	24 ± 5.33	----	24

TABLE VII. ANALYSIS OF VARIANCE FOR AGE OF DAM EFFECTS

Source of Variation	d.f.	Mean Square	F
Correction Factors From This Study			
Total	240		
Between Years	6	104,925	42.24 **
Age of Dam-Year Subclass	48	18,329	7.38 **
Age of Dam Within Subclass	42	5,959	2.40 **
Within	192	2,484	
Correction Factors from Minyard (1959)			
Total	240		
Between Years	6	94,832	29.87 **
Age of Dam-Year Subclass	48	16,380	5.16 **
Age of Dam Within Subclass	42	5,172	1.63 *
Within	192	3,175	

** Highly Significant ($P < 0.01$)
* Significant ($P < 0.05$)

Effects of Inbreeding

Coefficients of inbreeding averaged 10 percent for the progeny and four percent for the parents in this study. The inbreeding for individual animals ranged from 0 to 33 percent.

The effects of inbreeding on the various traits were calculated from the variance--covariance analyses given in Table VIII. The linear regressions, used in correcting the data, were computed from within year-sire subclasses. Table IX shows the regression analyses for all three traits. The effects of inbreeding on type score were significant at the 0.05 level of probability. Inbreeding effects on weaning weight and 12-month weight were significant at the 0.01 level of probability. The following regression coefficients were calculated:

weaning weight - 1.99 ± .45 pounds per one percent inbreeding

12-month weight - 2.23 ± .56 pounds per one percent inbreeding

12-month type score - 0.04 ± .02 units per one percent inbreeding

Using the regression of weaning weight on inbreeding - 1.99, a heifer that is 25 percent inbred would be expected to weigh 50 pounds less at weaning than a non-inbred. If the age and age of dam adjusted weight for the heifer was 397 pounds, her weight corrected for inbreeding would be 447 pounds. The regression coefficient obtained for type score indicates an increase in inbreeding of 25 percent would be necessary to lower the average type classification one-third of a grade.

The regressions of weaning weight, 12-month weight and 12-month type score on inbreeding were statistically analyzed for the possibility of curvilinearity. The second degree polynomial method described by Snedecor (1956) was used for this purpose. There were no significant deviations from linearity for the effects of the heifer's inbreeding on weaning weight or 12-month weight. However, a significant deviation from linearity for the effect of the heifer's inbreeding on 12-month type score was obtained. The curvilinearity of the regression of 12-month type score on inbreeding was significant at the 0.01 level of probability. This study, therefore, indicates inbreeding does have a curvilinear depressing effect on 12-month type score for range beef heifers.

TABLE VIII. ANALYSES OF VARIANCE AND COVARIANCE

Source of Variation	d.f.	Inbreeding W	WX	Weaning Weight X	WY	12-month Weight Y	WZ	12-month Type Score Z
Total	284	2.97	- 327.86	663,634.41	- 161.86	1,485,439.25	- 45.32	933.49
Sire-Year Subclass	46	2.07	- 148.30	191,403.03	39.71	769,296.89	- 42.02	285.98
Within Subclass	238	0.90	- 179.56	472,231.38	- 201.57	716.142.36	- 3.30	647.51

TABLE IX. REGRESSION ANALYSES

Source of Variation	d.f.	S.S.	M.S.	F	b_{yx}	r_{xy}
Inbreeding on Weaning Weight						
Due to Regression	1	35,667.03	35,667.03	19.35 **	- 1.99	- 0.27
Not Accounted For	237	436,743.91	1,842.80			
Total	238	472,410.94				
Inbreeding on 12-month Weight						
Due to Regression	1	44,986.40	44,986.40	15.88 **	- 2.23	- 0.25
Not Accounted For	237	671,357.53	2,832.73			
Total	238	716,343.93				
Inbreeding on 12-month Type Score						
Due to Regression	1	12.10	12.10	4.50 *	- 0.04	- 0.14
Not Accounted For	237	638.70	2.69			
Total	238	650.81				

Heritability Estimates

Paternal half-sib heritability estimates were obtained for weaning weight, 12-month weight and 12-month type score. The analyses of variance and covariance from which the sire components were calculated are presented in Table X. Table XI presents the sire components and within sire mean squares that were obtained from these analyses of variance and covariance. The geometric or weighted mean number of progeny within each sire group (K_o) is 6.0369.

The intraclass correlations, half-sib heritability estimates and the fiducial limits for each trait are presented in Table XII. The intraclass correlations were derived by dividing B by A + B. To correct for the greater relationship between half-sibs due to inbreeding, the multiplier used in obtaining the heritability estimates from the intraclass correlation, was calculated by the formula presented by Lush (1948). The average inbreeding of the progeny was 10 percent while that of the parents averaged four percent. The multiplier used in this study was 2.6732. The fiducial limits were calculated according to the method described by Hazel and Terrill (1945).

TABLE X. ANALYSIS OF VARIANCE AND COVARIANCE FOR WEANING WEIGHT (X), 12-MONTH WEIGHT (Y) AND 12-MONTH TYPE SCORE (Z)

Source of Variation	d.f.	Theoretical Composition	Mean Squares X	Mean Squares Y	Mean Squares Z	Cross-products XY	Cross-products XZ	Cross-products YZ
Between Sire Groups [a]	39	$A + K_0B$	3,918.15**	6,570.84**	5.22**	4,162.16	28.84	42.95
Within Sire Groups	238	A	1,827.25	2,807.83	2.67	1,823.46	28.21	41.76

[a] Within Year Subclass
** Highly Significant ($P < 0.01$)

TABLE XI. SIRE COMPONENTS AND WITHIN SIRE MEAN SQUARES

Traits	Sire Component (B)	Within Sire Mean Square (A)
Weaning Weight	346.35	1,827.25
12-month Weight	623.34	2,807.83
12-month Type Score	0.42	2.67

TABLE XII. INTRACLASS CORRELATIONS, HERITABILITY ESTIMATES AND FIDUCIAL LIMITS

Traits	Intraclass Correlations	Heritability Estimates	Fiducial Limits
Weaning Weight	.1593	.4258	± .1849
12-month Weight	.1817	.4857	± .1912
12-month Type Score	.1366	.3652	± .1778

Genetic, Environmental and Phenotypic Correlations

The genetic, environmental and phenotypic correlations calculated for weaning weight and 12-month weight, weaning weight and 12-month type score and 12-month weight and 12-month type score were derived from the analysis of variance and covariance on the same data used in the heritability study. Table X contains the analysis of variance and covariance for the traits under consideration.

Table XIII contains the genetic, environmental and phenotypic components of variance and covariance. In a partially inbred population, where the relationship between half-sibs is greater than one-fourth, the sire component will contain more than one-fourth of the genetic variance. Correspondingly, the genetic variance in the within sire mean square will be less. In deriving the genetic variance, the sire component is multiplied by the factor 2.6732. The factor used in deriving the environmental components was 1.6732. This factor is an estimation of the number of sire components present in the within sires mean square and was derived in the STATISTICAL ANALYSIS section.

TABLE XIII. GENETIC, ENVIRONMENTAL AND PHENOTYPIC COMPONENTS OF VARIANCE

Traits		Weaning Weight X	12-Month Weight Y	12-Month Type Score Z
Weaning Weight (X)	Genetic	925.87	1035.60	.28
	Environmental	1247.77	1175.30	28.04
	Phenotypic	2173.64	2210.90	28.31
12-month Weight (Y)	Genetic		1666.30	.53
	Environmental		1764.93	41.43
	Phenotypic		3431.23	41.96
12-month Type Score (Z)	Genetic			1.13
	Environmental			1.96
	Phenotypic			3.09

The correlations derived from these data are presented in Table XIV. It would appear from the genetic correlations between weaning weight and 12-month type score and between 12-month weight and 12-month type score that the gain of an animal, as indicated by his weaning weight and 12-month weight, is genetically independent of his conformation or type.

TABLE XIV. GENETIC, ENVIRONMENTAL AND PHENOTYPIC CORRELATIONS

Traits		12-month Weight	12-month Type Score
Weaning Weight	Genetic	.834	.009
	Environmental	.792	.566
	Phenotypic	.810	.345
12-month Weight	Genetic		.012
	Environmental		.704
	Phenotypic		.407

Selection Indices

Seven selection indices were constructed by combining weaning weight, 12-month weight and 12-month type score in all possible combinations. The statistical information required for construction of the indices is presented in Table XV.

The relative economic values in Table XV were discussed under Selection Indices in the STATISTICAL ANALYSIS section. The rest of the information contained in Table XV was derived from the analysis of the data in this study according to methods previously discussed.

The multiple regression coefficients and the correlations between the aggregate genotype and the various indices are given in Table XVI. The amount of genetic progress expected when a given index is used in making selections is proportional to the correlation between the aggregate genotype and the given index (R_{IH}). Comparison of the R_{IH} values indicate that indices one and two will give the maximum genetic progress considering all seven methods of selection. Where weaning weight, 12-month weight and 12-month type score are combined in index one, 12-month type score receives negative attention. The use of this index would bring selection pressure against type score. If heifers of equal weaning weight and 12-month weight were being selected on the basis of index one, the heifer with the lower type score would be given priority as a replacement. The regression coefficient for 12-month type score is negative only when it is combined with both weaning weight and 12-month weight in a selection index.

The R_{IH} value for index two indicates that progress would be just as rapid where 12-month type score is omitted and selection is based on weaning weight and 12-month weight. Hence, it would appear from this study that 12-month type score contributes very little to an index that includes weaning weight and 12-month weight.

Index six compared to index two indicates that index two is 69.9 percent more efficient in improving the overall genetic value. Although 12-month weight includes weaning weight, selection for 12-month weight alone is not as efficient as selection based on both weaning weight and 12-month weight. Selection based on weaning weight, 12-month weight and 12-month type score (I_1) is 250.8 percent more efficient in bringing about genetic progress than index seven where selection is based on 12-month type score alone.

TABLE XV. STATISTICAL INFORMATION REQUIRED FOR CONSTRUCTION OF THE INDICES

Character	Economic Value	Standard Deviation	h^2	Phenotypic Correlations		Genetic Correlations	
				(2)	(3)	(2)	(3)
Weaning Weight (1)	.27	46.622	.426	.810	.345	.834	.009
12-month Weight (2)	.25	58.577	.486		.407		.012
12-month Type Score (3)	5.43	1.759	.365				

TABLE XVI. COMPARISON OF SELECTION INDICES

Character	Indices I_1	I_2	I_3	I_4	I_5	I_6	I_7
Weaning Weight	.081	.080	.102		.115		
12-month Weight	.162	.151		.117		.121	
12-month Type Score	-.899		1.074	.438			1.981
R_{IH}	.656	.649	.305	.386	.288	.382	.187

DISCUSSION AND CONCLUSIONS

The purpose of this study was to investigate weaning weight, 12-month weight, and 12-month type score as possible criteria to be used in the selection of replacement heifers. Seven selection indices were calculated based on all possible combinations of these traits. The information necessary for the construction of these indices was calculated from data accumulated over an eight year period (1952-1959) on 285 Hereford heifers, the progeny of sixteen sires.

The weaning and 12-month weights were corrected for age, age of dam and inbreeding. Correction was also made for the effects of inbreeding on 12-month type score. It is well recognized that the age of an animal has a significant effect on its weight. Minyard (1959) found a highly significant linear regression of 1.20 for weaning weight on weaning age. Hitchcock, et al. (1955) reported a partial regression coefficient of 1.09 for yearling weight on yearling age. The weaning weights in this study were adjusted to a 190 day basis by using linear correction factors developed by Johnson and Dinkel (1951). These factors were considered appropriate because the weaning weight records used by Johnson and Dinkel in their study were from calves raised under conditions similar to those of this study. The yearling weights were corrected for age by the following formula:

$$W = A + B$$

where: W = age adjusted yearling weight

A = age adjusted weaning weight

B = gain to yearling weight

Age of dam differences for 12-month weight were significant at the 0.01 level of probability. To reduce the variance due to age of dam, correction factors were calculated according to the procedure presented by Koch and Clark (1955). According to this procedure, two methods (A & B) were used in calculating the age of dam effects. Due to concurrent selection these methods are biased in opposite directions. Hence, an unbiased estimate was obtained by combining the estimates derived by the two methods. Estimates of age of dam effects calculated by Method B were larger than those calculated by Method A. This is just the opposite of what would be expected, since Method A is biased upward and Method B is biased downward. It would be more likely to expect deviations computed by Method B to be smaller than those computed by Method A, at least for cows below eight years of age. In Method B, records made by the same cow at two different ages are compared. Since consecutive records made by the same cow must necessarily fall in different years, environmental variation between years could effect these records. Therefore, a possible explanation for the large deviations found between estimates computed by Method B might be the fact that the records used were not corrected for year effects. Another explanation might be the small numbers available in this study for calculating the age of dam effects by Method B as indicated by the large standard errors associated with these estimates. When the estimates computed by Method A & B were combined and these factors were then applied to the data, the variance due to age of dam differences was not sufficiently reduced. The failure of the correction factors to reduce the age of dam variance was probably due to the inaccurate estimates computed for age of dam effects by

Method B.

Minyard (1959) developed age of dam correction factors for weaning weights by the same method used in this study. The 12-month weights were corrected according to these factors and an analysis of variance was computed as before. The reduction in age of dam within subclass variance was greater using Minyard's factors than it was using the factors developed in this study. Although the age of dam differences were not entirely removed by these factors, they were considered to be the most useful and were used in correcting the data.

In this study, as in others, growth rate and type score were affected by inbreeding. The effects of inbreeding were significant at the 0.01 level of probability for weaning and 12-month weight and at the 0.05 level of probability for 12-month type score. The average inbreeding of the progeny was 10 percent, while that of the parents was four percent. The regressions were calculated from a within year-sire subclass after the weight characteristics had been adjusted for age and age of dam. The estimated regression of weaning weight on inbreeding of the individual was - 1.99 pounds per one percent inbreeding. Significant regressions of weaning weight on inbreeding have been reported by Koch (1951) and Burgess et al. (1954). The mean inbreeding in these two studies was 12.4 and 30 percent, respectively. The linear regression reported by Koch was - .48. The regression of - 1.75 obtained by Burgess, more nearly corresponds to the estimate obtained in this study.

The reduction in 12-month weight due to inbreeding of the individual was - 2.23 pounds per one percent inbreeding. This corresponds to the intra-sire regression of 12-month weight on inbreeding of - 2.74 reported by Nelson and Lush (1950). Their study was made on Holstein-Friesian cattle with inbreeding coefficients ranging from zero to 28 percent. Nelson and Lush found that the regression coefficient increased up to two years. That this is the case with range beef heifers is not known, however, the indications from this study are that the effects of inbreeding on weight increase from weaning to 12-months of age.

The regression coefficient of 12-month type score on inbreeding was found to be - 0.04 units per one percent inbreeding. This is identical with the intra-sire regression of 12-month type score on inbreeding in dairy cattle obtained by Nelson and Lush (1950). The effects of inbreeding on weaning weight, 12-month weight and 12-month type score were corrected according to the regression coefficients obtained in the present study.

Statistical analyses were made to determine whether the regressions of weaning weight, 12-month weight and 12-month type score on inbreeding are curved. The second degree polynomial method described by Snedecor (1956) was used for this purpose. The deviations from linearity for the effect of the heifer's inbreeding on weaning weight and 12-month weight were not significant. However, a significant deviation from linearity at the 0.01 level of probability was obtained for the effect of the heifer's inbreeding on 12-month type score. Zoellner (1957) found that inbreeding has a curvilinear depressing effect on weaning weight, 18-month weight and 18-month type score for range beef heifers. His study was made on records from 303 unselected heifers raised by the South Dakota Agricultural Experiment Station. Part of these records taken between 1952 and 1955 were used in the present study.

Heritability estimates for weaning weight, 12-month weight and 12-month type score derived from these data, were calculated by the paternal half-sib correlation method. The data used in obtaining these estimates were corrected for age, age of dam and inbreeding. Sire components and within sire mean squares were obtained from an analysis of variance and covariance analyzed on a within year subclass basis. The paternal half-sib heritability estimate for weaning weight was .43. This estimate falls within the range of the estimates reported by other researchers but is higher than most of the reported estimates. Since the data used in estimating heritability were collected from single-sire inbred lines, estimates of sire effect will be biased upward from the cows not being randomly allotted, pasture differences between lines (and sires), and any other effect peculiar to an individual line. This may, in part, account for the heritability estimates being somewhat high.

The heritability estimate of .49 obtained for 12-month weight does not represent an estimate for a standard age. Each year the length of the feeding period following weaning varied with pasture conditions. The average length overall years was 195 days. The 12-month weights were adjusted to a constant age within each year. Therefore, the estimate of heritability for 12-month weight is a combined estimate. The 12-month weights in this case most nearly represent age at 385 days. The rancher is likely to weigh his cattle at a given date within each year, but in general this date will not be constant from year to year, due to pasture conditions and other practical considerations. The estimate of heritability in this study, therefore, has greater practical application in that it is representative of the conditions that are likely to occur in range cattle production. It compares favorably with those heritability estimates reported for fall yearling weight by Koch and Clark (1955a) and Wagnon and Rollins (1959). The paternal half-sib estimate obtained by Koch and Clark was .47. Wagnon and Rollin's paternal half-sib estimate for long yearling weight was .44.

The heritability estimate obtained for 12-month type score in this study was .37. It is considerably higher than the estimates of .18 and .14 computed by Koch and Clark (1955a and 1955b) using the paternal half-sib method and regression of offspring on dam method, respectively.

Genetic, environmental and phenotypic correlations were obtained for weaning weight and 12-month type score. As might be expected, the genetic correlation between weaning weight and 12-month weight was high (.83). The genetic correlations between weaning weight and 12-month type score (0.01) and between 12-month weight and 12-month type score (0.01), are considerably lower than the same correlations of .23 and .49, respectively, reported by Koch and Clark (1955a). The correlations reported by Koch and Clark were estimated from weaning weight, fall yearling weight and type score records on 4,553 Hereford calves. The low genetic correlations between the two weight traits and 12-month type score indicate that the type of an animal is not influenced by the same genes that the weight traits are dependent upon for their expression.

The selection indices were developed according to the method outlined by Hazel (1943). Correlations between each of the seven indices and the aggregate genetic value were calculated and used as a means of comparing the efficiency of the indices in bringing about genetic progress. From the present study, two indices (I_1 and I_2) were calculated that should provide maximum genetic progress from selection. A negative regression coefficient for type score was obtained in index one where selection is based on weaning weight, 12-month weight and 12-month type score. The use of this index would bring selection pressure against type score. Negative regression coefficients for type score have been obtained in swine but they have not been previously reported for beef cattle. Hazel (1943) suggests that if the phenotypic correlation is large as compared to the genetic correlation, the regression coefficient for a trait with little economic importance or slight heritable variation may be negative, as its function in the index then becomes mainly that of indicating the environment for a more important trait. In this study the phenotypic correlation for type score is larger than the corresponding genetic correlation. The economic value for type score, however, does not fit the situation described by Hazel. Type score was given the highest economic value of the three traits. It is probably too high, due to the fact that the unit of measurement in the graded score is actually 1/3 of a market grade whereas in calculating the economic value it was considered a full grade. In view of this, the estimates of the importance of type score in these indices should be considered as a maximum. The exact reason for the negative regression coefficient for type score is unknown. It is interesting, however, that negative attention is assigned to 12-month type score only when it is in combination with weaning weight and 12-month weight in a selection index. The fact that the environmental correlations between weaning weight and 12-month type score (.566) and between 12-month weight and 12-month type score are high (.704) would indicate that the same environmental circumstances tended to influence all three characteristics in the same way. Secondly, the fairly large phenotypic correlations between weaning weight and 12-month type score (.345) and between 12-month weight and 12-month type score (.407) would indicate that the heifers biggest for their age also tend to receive the highest scores. Thus selection for weight would create some improvement for type score because of the positive genetic correlation between type score and the weight traits. Therefore, the negative regression coefficient for type score in index one would seem to suggest that more attention should be paid to weight for age than should be paid to type score. This is also indicated by the fact that index two, where selection is based on weaning weight and 12-month weight, is equivalent in practical value to index one. However, to the extent that the phenotypic correlations between weaning weight and 12-month type score and between 12-month weight and 12-month type score arise because all three traits were influenced by the same environmental circumstances, selecting against type score might be a useful means of discounting the effects of that common environment on the other two traits.

According to this study indices one and two will give the maximum genetic progress of the seven indices calculated. The progress which can be made by using index one, which includes all three traits, is 66 percent of that which could be made with a perfect index. The efficiency of index two, where selection is based on weaning weight and 12-month weight, is 65 percent of that which could be made with a perfect index. According to the R_{IH} values, the expected genetic progress using indices one and two is comparable. Due to the fact that weaning weight represents a considerable portion of the 12-month weight, it would appear that selection on 12-month weight alone should be comparable to selection based on both weaning weight and 12-month weight. According to this study, however, selection based on weaning weight and 12-month weight (I_2) is 69.9 percent more efficient in bringing about genetic progress than index six where selection is based on 12-month weight alone. It would appear from this that both weaning and 12-month weight need to be considered in an index if maximum genetic progress for these traits is to be obtained.

Zoellner (1957) developed seven selection indices for range beef heifers by combining weaning weight, 18-month weight and 18-month type score in all possible combinations. His data included records from 303 heifers raised by the South Dakota Experiment Station during the period 1948 to 1955. A portion of these records (1952 to 1955) were used in the present study. The most efficient selection index according to Zoellners study included; weaning weight, 18-month weight and 18-month type score. The precision of predicting the aggregate genetic value of an animal by this index was .628. The results indicated that the index using 18-month weight alone was equally as efficient, as indicated by an R_{IH} value of .624.

Lindholm and Stonaker (1957) determined the economic importance of weaning weight and grade, daily gain, days to finish, slaughter grade, feed per pound of gain, and cow maintenance costs in determining net income in a calf raising and feeding operation. The data consisted of observations on 118 Hereford steers by 19 sires. The indices developed from the above characteristics indicate that weaning weight alone is an accurate basis for selection. The results of these studies by other authors as well as the present study indicate the importance of selecting on one or more weight characteristics.

The primary reason for using an index is to compare animals for overall merit. Comparing animals for three or more characteristics at the same time without over or underemphasizing certain traits is extremely difficult using methods other than a selection index. A breeder may try to pay attention to too many things in his selections, thus weakening the intensity of selection for the more important things. A selection index overcomes such errors by giving a definite purpose and direction to selection. The right combination of characteristics and the weight to be given each characteristic in order to return to the breeder the maximum income is determined by emphasizing each characteristic in proportion to the product of its heritability (that is, the amount transmitted from parent to offspring for each characteristic) and its economic importance. The best selection index will weight each characteristic in such a way as to bring about maximum improvement in the transmitting ability of the herd.

For application purposes, the indices developed in this study may be simplified. For example, index one may be written as follows:

$$I_1 = .08\ X_1 + .16\ X_2 - .90\ X_3$$

where, X_1 is the weaning weight at 190 days, X_2 represents the 12-month weight and X_3 the 12-month type score. By substituting the phenotypic performance of the three traits in place of the X's and multiplying through the formula, a total score may be obtained for each animal. A selection index ranks the animals from the best to the poorest according to their total score. Replacements for the cows culled in a beef herd would then be selected from the top indexing heifers.

SUMMARY

The purposes of this study were to investigate the genetic and environmental factors that influence economic characteristics of range beef heifers and to develop a selection index that would permit the attainment of maximum genetic progress in the selection of replacement heifers for the beef herd. The characteristics studied were weaning weight, 12-month weight and 12-month type score. In order to obtain the desired indices, heritability estimates, standard deviations, and genetic, environmental and phenotypic correlations were calculated. Since some of the heifers were produced in inbred lines, study of the effects of inbreeding was necessary in order to be able to adjust for differences in inbreeding. Hence, regression coefficients of the three traits on inbreeding of the individual were calculated. Heritability estimates were determined for the various traits by the paternal half-sib correlation method. Genetic, environmental and phenotypic correlations were calculated for weaning weight and 12-month weight, weaning weight and 12-month type score and for 12-month weight and 12-month type score. Seven selection indices were constructed and the effectiveness of each was determined by the correlation between the respective index and the aggregate genetic value.

The data included records from 285 purebred Hereford heifers, the progeny of sixteen sires. The heifers were born over an eight year period 1952 to 1959 inclusive, at the Antelope Range Field Station. Correction factors were used to adjust the data for age, age-of-dam and inbreeding differences. The analysis of variance and covariance was

used in the analysis of these data, and the results are as follows:

1) Age of dam correction factors developed from these data were not considered valid due to large sampling errors, the result of inadequate numbers.

2) The study indicated that weaning weight, 12-month weight and 12-month type score of a calf are significantly influenced by its inbreeding. Deviations from linearity for the effect of the heifer's inbreeding on weaning weight and 12-month weight were not significant. Curvilinearity was found for the effects of inbreeding on 12-month type score.

3) The regression of weaning weight on the inbreeding of the individual was - 1.99 pounds per one percent inbreeding. The estimated regression of 12-month weight on inbreeding of the individual was - 2.23 pounds per one percent inbreeding, and the 12-month type score estimate was - 0.04 units per one percent inbreeding.

4) The paternal half-sib heritability estimates obtained in this study were 43, 49 and 37 percent for weaning weight, 12-month weight and 12-month type score, respectively.

5) The genetic correlations calculated in this study are as follows: weaning weight and 12-month weight .83, weaning weight and 12-month type score 0.01 and 12-month weight and 12-month type score 0.01.

6) From the seven indices constructed in this study, two (I_1 and I_2) are to be worthy of consideration. Index one, where weaning

weight, 12-month weight and 12-month type score are considered, has a R_{IH} value of .656. Where selection is based on weaning weight and 12-month weight (index two), the R_{IH} value is .649.

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